CHAPTER 1

Land Application of Biosolids: A Prospective

INTRODUCTION

The United States Environmental Protection Agency (USEPA) accepts the term *biosolid* for sewage sludge that is treated to meet the regulations in 40CFR503 (USEPA, 1994). Moreover, the term *sludge* is used for many different materials, both inorganic and organic. A better term would be sewage biosolids, because it indicates the biological nature of the residual and its origin. Many organic residuals, e.g., paper mill sludges, are biological and could be classified as biosolids. In this text, biosolids will be used to designate treated sewage sludge that meets USEPA Class A or B. Raw sludge, e.g., primary, waste-activated, secondary sludge, and those materials that do not meet the USEPA Class A or B will still be designated as sewage sludge.

Biosolids are derived from the treatment of wastewater. The wastewater, primarily derived from domestic sources, is treated at a publicly owned treatment works (POTW). This wastewater will also contain discharges from commercial and industrial enterprises. Many of these enterprises conduct pretreatment prior to discharging wastes into the sewer system. As a result of pretreatment, which was enforced by the Clean Water Act of 1974, biosolids have become less contaminated with trace elements that include heavy metals and organic compounds.

The predominant wastewater treatment processes are primary and secondary treatment. Tertiary treatment may be necessary before discharge of the clean effluent is allowed into certain classes of water bodies. Both the nature of the domestic waste and the secondary treatment, which is a biological treatment, result in sludge being predominantly organic matter.

Solids in the wastewater stream are removed during primary and secondary treatment. This sewage sludge, if it does not undergo further treatment, is often referred to as raw sludge. It is usually incinerated, landfilled or further treated. Further treatment may consist of digestion, composting or alkaline stabilization.

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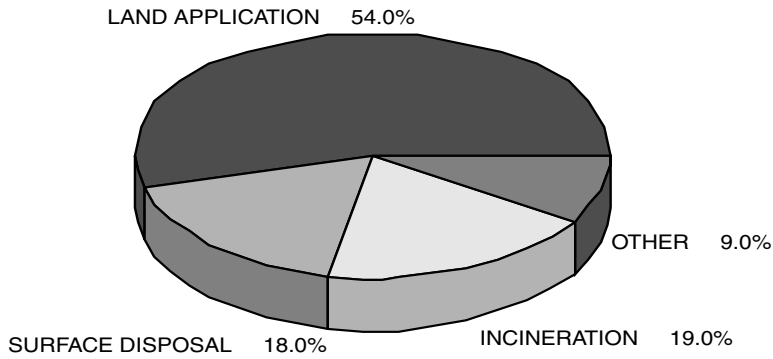

Figure 1.1 Use and disposal of sewage sludge and biosolids in the United States (USEPA, 1993).

After treatment, this material is called biosolids. Biosolids will contain inorganic material, plant nutrients, trace elements, organic compounds, and pathogens. (More data on characteristics of biosolids are presented in Chapter 2.) The organic nature of biosolids, along with plant nutrients and several trace elements, which are micronutrients for plants, makes it a valuable resource for land application. However, high concentrations of several trace elements, toxic organic compounds, and pathogens can preclude the beneficial use of biosolids.

USE AND DISPOSAL OF SEWAGE SLUDGE AND BIOSOLIDS

The USEPA in 1998 estimated that approximately 6,232,880 metric tons (tonnes) or 6,856,168 dry tons are generated annually in the United States. In its September 1999 report entitled Biosolids: Generation, Use, and Disposal in the U.S., the agency estimated that 7.1 million tons would be generated in 2000 and 8.2 million tons by 2010. The distributions for the most common methods of disposal or utilization are shown in percentage terms in Figure 1.1. Distribution and marketing, which include composting and heat drying, were estimated at approximately 3%. Ocean disposal has been discontinued since 1992. Because disposal to landfills has been severely curtailed in many states, land application has increased. Incineration is also decreasing because many incinerators cannot meet the Clean Air Act regulations or the USEPA 503 regulations.

In the United States there are vast differences in the way biosolids or sewage sludge is utilized or disposed. These differences, compiled by Bastian (1997), show that in New England and the Northeast less than 30% is land applied (Table 1.1).

A significant amount of biosolids from the Northeast is shipped out of state for either land application or landfills. Nearly 90% of the biosolids produced in the Northwest are land applied.

Table 1.2 compares the use and disposal of sludge and biosolids in 1989 and 1997. In that 9-year timeframe, land application that includes composting, heat drying, and other products that are distributed or marketed increased by 12%, landfilling and surface disposal decreased, incineration increased, and ocean disposal ceased.

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Table 1.1 Biosolids/Sewage Sludge Utilized or Disposed by USEPA Regions in the United States

Region	Population served by POTWs[1]	Total biosolids/ sludge production (dmt/yr)	Percent used/disposed by:			
			Land application[2]	Surface disposal[3]	Incineration	Other
I. New England	8,037,311	367,430	24	46	30	–
II. Northeast	21,726,101	605,046	30	14	23	33[4]
III. Mid Atlantic	18,152,556	1,040,206[5,6]	74	16	10	<1
IV. Southeast	24,510,111	1,050,325[5]	57	30	12	1
V. North Central	35,587,804	1,705,316	51	2	30	17[7]
VI. South Central	21,150,172	425,203[5]	53	45	2	–
VII. Midwest	9,036,498	511,712[5]	65.5	4	25.5	5
VIII. Rocky Mountains	6,262,873	111,880[5]	68	29	0	3[7]
IX. Southwest	30,432,899	819,050	51	36	4	9[7]
X. Northwest	5,634,539	220,000	89	2	9	–
U.S. Totals	180,530,874	6,856,168[6]	54	18	19	9

[1] Based on 1992 Needs Survey Data (USEPA, 1993).

[2] Includes all forms of land application practices, such as application of liquid, dewatered cake, dried, composted, alkaline stabilized, or otherwise processed product to cropland, forests, reclamation sites, lawns, parkland, etc.; use as organic fertilizer or soil amendment; use in potting mixes and the production of topsoil, etc. (including use as a daily or final landfill cover as land application).

[3] Includes co-landfilling with solid waste; monofilling; permanent disposal in piles or lagoons, etc.

[4] Shipped out of state for use/disposal (mainly by land application and landfill).

[5] Includes estimates based upon population served by POTWs and regional conditions.

[6] Some estimates (based upon the number of households served by POTWs) of total production for Pennsylvania would increase this number by 1,578,639 dmt/yr.

[7] Long-term storage.

Source: Bastian, 1997, *Eur. Water Pollut. Control* 7(2): 62–78. With permission.

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Table 1.2 A Comparison of Sludge and Biosolids' Use or Disposal in The United States in 1989 and 1997

Use or Disposal	1989*	1997**
Land application & distribution and marketing	42	54
Landfill, monofill and surface disposal	24	18
Incineration	11	19
Ocean	3	0
Other	12	9

* USEPA analytical survey (USEPA, 1990).
** Bastian, 1997.

At the same time, the quality of biosolids has improved. Examples of some reductions of heavy metals at several wastewater treatment plants are shown in Table 1.3. (More detail on the characteristics of sludge and biosolids is provided in Chapter 2.)

Bastian (1997) reported that biosolids production in the United States has constantly increased. Over the past 10 to 20 years, not only have there have been major changes in sewage sludge/biosolids management practices, but also significant changes in equipment (Bastian, 1997). These include:

1. Expanded use of mechanical dewatering equipment and polymers.
2. A shift from the use of multiple hearth incinerators to fluid bed incinerators.
3. Less long-term lagoon storage.
4. Less use of landfilling with municipal solid waste, but an increase in use as a daily or final landfill cover material.
5. Increase in use of land application.
6. Increase in use of heat drying, pelletizing, composting, and alkaline stabilization processing of biosolids to generate products.
7. A phase-out of ocean dumping.
8. More long-distance transport of biosolids to end use/disposal sites.
9. Increase in energy recovery from incinerators, landfills, and anaerobic digesters.
10. Increase of contracted-out biosolids management operations.
11. Increase in multiple biosolids use and disposal practices, especially by the large authorities.

Bastian (1997) indicates that several factors influenced these trends in sewage sludge/biosolids processing and use/disposal practices:

1. Dramatic increases in biosolids production.
2. Improvement in quality of biosolids as a result of industrial pretreatment.
3. Improvements in biosolids handling equipment and processing.
4. Improvement in biosolids management practices.
5. Increase in costs for urban land, labor, and energy.
6. A willingness of management agencies to pay dramatically higher prices for biosolids processing, beneficial use, and disposal.
7. More information from research and development and monitoring activities.
8. Changes in regulatory policies and requirements.
9. Increase in public sensitivity on environmental and health issues and negative public reactions to biosolids processing sites and disposal facilities.

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Table 1.3 Examples of Several POTWs Demonstrating Reductions in Biosolids' Heavy Metals

POTW (actual flow)	Source Years	Reported Reductions in Loadings to Biosolids
Bowling Green, KY (5 mgd)	1985–1988	Zn – 97%; Pb – 90% Cr – 72%; Ni – 100% Cd – 91%; Cu – 88%
Pocatello, ID	1985–1988	Zn – 45%; Pb – 36% Cr – 67%; Ni – 56% Cd – 57%; Cu – 43%
Albany, NY (7 mgd)	1983–1987	Zn – 94%; Pb – 98% Cr – 99%; Ni – 99% Cd - <50%; Cu – 99%
Springfield, OH (19.9 mgd)	1984–1989	Zn – 77%; Pb – 87% Cr – 79%; Ni – 50% Cd – 79%; Cu – 53%
Oswego, IL (22.8 mgd)	1985–1990	Zn – 56%; Pb – 47% Cr – 92%; Ni – 78% Cd – 96%; Cu – 50%
Louisville and Jefferson County, KY (97.9 mgd)	1982–1989	Zn – 79%; Pb – 68% Cr – 74%; Ni – 25% Cd – 83%; Cu – 54%
Metro Seattle, WA (156 mgd)	1981–1989	Pb – 46%; Cd – 38% Cu – 56%

Source: Bastian, 1997, *Eur. Water Pollut. Control* 7(2): 62–78. With permission.

More recent factors that are influencing biosolids management practices are land application bans, incinerator air emissions, and odors from composting operations.

Matthews (1999) reported on management methods in Europe. Table 1.4 shows his data. Disposal methods vary considerably in the different European countries. Matthews indicates that sludge/biosolids production in the European Union will have doubled from 1992 to 2002. Marine disposal will be discontinued, putting more pressure on land-based methods of utilization and disposal. In Greece, for example, 90% of the biosolids was landfilled. On average in Europe, 36.4% of the biosolids was used in agriculture; 41.6% were landfilled; and 10.9% was incinerated. The remaining 11.19% was dumped into the ocean or surface waters, or used for other purposes such forestry or recultivation.

SYSTEMS FOR THE USE OR DISPOSAL OF SEWAGE SLUDGE AND BIOSOLIDS

There are several options for the disposal or utilization of biosolids:

- Direct land application
- Composting and land application

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Table 1.4. Biosolids Production and Disposal Methods in Europe

Country	Quantity 1000 dry tonnes/ year	Agriculture	Landfill	Incineration	Sea	Other (e.g., recultivation, forestry)
				Percent		
Austria	170	18	35	34	–	13
Belgium	59.2	29	55	15	–	1
Denmark	170.3	54	54	40.9	–	2
Finland	150	25	75	–	–	–
France	865.4	58	27	15	–	–
Germany	2681.2	27	54	14	–	5
Greece	48.2	10	90	–	–	–
Ireland	36.7	12	45	–	35	8
Italy	816	33	55	2	–	10
Luxembourg	8	12	88	–	–	–
Netherlands	335	26	51	3	–	20
Norway	95	58	44	–	–	–
Portugal	25	11	29	–	2	58*
Spain	350	50	35	5	10	–
Sweden	200	40	60	–	–	–
Switzerland	270	45	30	25	–	–
UK	1107	44	8	7	30	11
Total	7387	36.4	41.6	10.9	5.19	6

* Surface waters

Source: Data from Matthews, 1999.

- Heat drying and land application
- Incineration
- Landfilling
- Dedicated land disposal

Direct land application can be beneficially used in agriculture, forestry, and land reclamation. The biosolids can be applied in either in a liquid form with low solids or as a semisolid following dewatering. Because of the nature of the material, in that it contains a large amount of water, it is often applied within relatively short distances. Exceptions include New York City, where dewatered, digested biosolids are rail hauled and applied as far as Texas and Colorado. Similarly, cities in southern California have some of their biosolids trucked to Arizona. Chicago Greater Metropolitan District barged liquid biosolids to Fulton County, a distance of approximately 200 miles, and then applied the liquid biosolids to agricultural land.

Direct land application for beneficial use involves some form of partial stabilization such as digestion or alkaline stabilization. Digestion results in USEPA 503 Class B biosolid whereas alkaline stabilization can result in a Class A or B product. The USEPA 503 regulations allow for either a Class A or Class B to be applied to land (see Chapter 12 for more information about regulations).

Application of biosolids for beneficial uses considers the crop requirement for the plant nutrients as well as the accumulation of trace elements. When sewage sludge or biosolids are land applied as a dedicated land disposal method, no crop

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is grown and the amounts applied are usually greater than when the biosolids are beneficially used.

Composting and heat drying are forms of land application. These technologies produce a USEPA 503 Class A product that provides for a wider range of uses. Today, most of these products meet the "Exceptional Quality" criteria for trace elements. The drier nature of these two materials provides for bagging and shipping to greater distances. Bagged composted animal manure has been shipped from California to Germany and heat-dried products are shipped from Massachusetts to Florida.

Biosolids compost is primarily used as a soil amendment and is valued for the organic matter content (Epstein, 1997). Its primary use today is in the horticultural field. However, recently farmers in several areas of the United States have been using compost to improve their soil's physical properties such as water holding capacity and soil structure. The nitrogen content of compost is lower than heat-dried biosolids. Therefore, larger quantities can be applied to improve the soil's physical properties. Heat-dried biosolids are considered as a fertilizer and applied at fertilizer rates. They may be used as a supplement to other inorganic fertilizer material to increase the plant nutrient content. Milorganite is an example of a heat-dried biosolid product from the city of Milwaukee, Wisconsin. It is widely used as a fertilizer in the turf industry.

HISTORY OF LAND APPLICATION OF SEWAGE SLUDGE AND BIOSOLIDS

References to land application of wastes can be found in the Bible (Deuteronomy 23:13 and Judges 3:20). The Greek and Romans understood the benefits of basic sanitation to society. In Ephesus, Turkey, steam-heated toilets were in place and wastes were flushed into the Aegean Sea. The author, in a visit to Ephesus, noted this continuous flushing system using heated marble toilets. Doxiadis (1973) also indicated that domestic wastes were conveyed to land application areas. In the 16th century, effluents were being used for crop production in Bunzlau, Germany. This practice began in 1550 and continued for 300 years (De Turk, 1935).

Jewell and Seabrook (1979) cited Gerhard (1909), who indicated that the earliest documented sewage farm or sewage irrigation system was in Bunzlau in 1531. In England, in 1859, a Royal Commission on Sewage Disposal recommended the application of town sewage to land as a means of avoiding river pollution (Webber and Hillard, 1974). Another early sewage farm was established in Edinburgh, Scotland around 1860. Major cholera epidemics in London in the mid-1800s that claimed more than 25,000 lives stimulated the treatment of sanitation facilities (Jewell and Seabrook, 1979). By 1876, 35 towns in Britain used land treatment. Large sewage farms were established in Paris, France (1869) and in Berlin, Germany (1874).

Between 1870 and 1880 there were 30 to 50 land application sites. Land application was just beginning in the United States (Jewell and Seabrook, 1979). The first sewage crop irrigation system in the United States was established in Augusta, Maine in 1872. By 1900 there were more than 10 places in the United States using

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Table 1.5 Some Early Land Application Systems

Location	Date started	Type of System	Area-ha	Flow m^3/d
International				
Croydon-Bedlington, England	1860	Sewage farm	255	21,198
Paris, France	1869	Slow rate infiltration	6,475	299,050
Leamington, England	1870	Sewage farm	162	3,785
Berlin, Germany	1874	Sewage farm	27,519	—
Worclaw	1882	Sewage farm	809	105,992
Melbourne, Australia	1893	Slow rate infiltration	4,209	189,272
		Overland flow	1,416	264,981
Braunschweig, Germany	1896	Sewage farm	4,452	60,567
Mexico City, Mexico	1900	Slow rate infiltration	45,360	215,770
United States				
Calumet City, Michigan	1886	Rapid infiltration	4.86	4,543
Woodland, California	1889	Slow rate infiltration	97	15,899
Fresno, California	1891	Slow rate infiltration	1620	98,421
San Antonio, Texas	1895	Slow rate infiltration	1620	75,709
Vineland, New Jersey	1901	Rapid infiltration	5.67	3,028
Ely, Nevada	1908	Slow rate infiltration	567	5,678

Source: Data from Fuller, 1983.

land treatment and by 1980 more than 4,000. Table 1.5 shows some selected land applications systems in Europe and the United States.

Anderson (1959) stated that the use of sewage sludge as a fertilizer dates essentially from 1927, when a large activated sludge treatment plant went into operation for the city of Milwaukee, Wisconsin. Table 1.6 shows the utilization of biosolids as fertilizer from 1930 to 1957 (Anderson, 1959). The author indicated that for sanitary reasons, activated sludge must be heat-treated before it is sold as fertilizer. He stated that digested biosolids should be heat-treated or incorporated into the soil for several months before application on vegetables.

Table 1.6 Utilization of Biosolids as Fertilizer from 1930 to 1957

Year	Dried Activated Biosolids		Dried Digested Biosolids	
	As Separate Material	As Mixed Fertilizer	As Separate Material	As Mixed Fertilizer
1930	14,852	17,811	—	—
1940	26,307	78,992	23,000	3,000
1945	29,261	61,306	30,274	5,791
1950	63,366	55,965	30,738	6,581
1953	69,494	—	36,719	—
1957	93,152	—	37,577	—

Source: Adapted from Anderson, 1959.

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Table 1.7 A Summary of the Major Wastewater Processes

Wastewater Treatment Level	Types of Sewage Sludge or Biosolids Produced
Screening and Grit Removal	
Wastewater screening removes coarse solids that can interfere with mechanical equipment. Grit removal separates heavy inorganic, sandlike solids that would settle in channels and interfere with the treatment processes.	Screening and grit are handled as a solid waste and nearly always landfilled. This material is not considered sewage sludge or biosolids and is not governed by USEPA 40CFR503 regulations.
Primary Wastewater Treatment	
Usually involves gravity sedimentation of screened, degritted wastewater to remove suspended solids prior to secondary treatment.	Sewage sludge by primary wastewater treatment usually contains 3%–7% solids; generally their water content can be easily reduce by thickening or dewatering.
Secondary Wastewater Treatment	
Generally relies on biological treatment (e.g., suspended growth or fixed growth systems), in which microorganisms are used to reduce biochemical oxygen demand and remove suspended solids. Secondary treatment is the minimum treatment level required for POTWs under the Clean Water Act.	Sewage sludge produced by secondary wastewater treatment usually has a low solids content (0.5% –2%) and is more difficult to thicken and dewater than primary sludge. Unstabilized solids can be landfilled or incinerated. Stabilization can result in the production of biosolids.
Tertiary (Advanced) Wastewater Treatment	
Used at POTWs that require higher effluent quality than that produced with secondary treatment. Common types of treatment include biological and chemical precipitation processes to remove nitrogen and phosphorus.	Lime, polymers, iron or aluminum salts used in tertiary wastewater treatment produce sewage sludge with varying water-absorbing characteristics. Also, high-level lime precipitation produces alkaline biosolids.

Source: Based on USEPA, 1999.

WASTEWATER TREATMENT AND BIOSOLIDS PRODUCTION

Wastewater treatment usually involves the following steps:

- Screening and grit removal
- Primary wastewater treatment
- Secondary wastewater treatment
- Tertiary (advanced) wastewater treatment
- Stabilization (biosolids production)
- Alkaline stabilization
- Anaerobic digestion
- Aerobic digestion
- Composting
- Heat drying and pelletizing

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Table 1.8. A Summary of the Stabilization Processes that Produce Biosolids

Stabilization Process	USEPA 40CFR503 Classification and Use
Alkaline Stabilization	
Use of lime or other alkaline materials, such as cement kiln dust, lime kiln dust, Portland cement and fly ash. Increase of pH to reduce pathogens and achieve vector attraction reduction.	The process can produce a Class A or Class B. Major uses are in agriculture, reclamation, slope stabilization, structural fill, and municipal solid waste (MSW) landfills.
Anaerobic Digestion	
Anaerobic digestion involves biologically stabilizing biosolids in a closed vessel to reduce the organic content, mass, odor, and pathogens. During this process methane is generated and can be used as an energy source. Both mesophilic temperatures (35°C, 95°F) and thermophilic temperatures (55°C, 131°F) are used.	The process produces either a Class B at mesophilic temperatures or Class A at thermophilic temperatures. The production of Class B is more common. Principal uses are in agriculture and forestry.
Aerobic Digestion	
Aerobic digestion utilizes oxygen or air to biologically stabilize biosolids in an open or closed vessel or lagoon. The organic matter is converted to carbon dioxide, water, and nitrogen. Pathogens and odors are reduced. High thermophilic temperatures are recently being used.	Generally in most cases a Class B biosolids is produced. High temperature systems can produce a Class A product. The principal uses are in agriculture.
Composting	
Composting is the biological decomposition of the organic matter. Generally biosolids composting is done at thermophilic temperatures (>55°C, 131°F) in order to destroy pathogens. During composting the odorous compounds are reduced.	Composting produces a Class A product. Its principal uses are horticultural, including landscaping, nursery operations, turf, lawn and sod production, agriculture, public works department projects, highway beautification and reclamation.
Heat Drying and Pelletizing	
Heat drying involves using active or passive dryers to remove water from biosolids. It is used to destroy pathogens and remove water, which reduces the volume of material. In some cases heat-dried products are formed into pellets.	Heat drying produces a Class A biosolids product. It is primarily used in agriculture. Other uses are in turf and sod production and golf courses. Heat dried pellets are also blended with other nitrogen, phosphorus, and potassium chemicals to produce fertilizers.

An extensive discussion of the stabilization processes is provided by Switzenbaum et al., 1997. Other discussions can be found in several documents produced by USEPA (USEPA, 1994; 1999). Table 1.7 summarizes some key features of the stabilization processes that produce biosolids.

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CONCLUSION

The advent of improved sanitation and wastewater treatment has resulted in the production of sewage sludge and biosolids. Increased public concern for environmental pollution of oceans, waterways, and the air has resulted in the increase in beneficial use. The increase in beneficial use, especially land application (including heat drying, composting, and alkaline stabilization), mandated that the quality of biosolids be improved. Industrial pretreatment requirements resulted in very significant reduction of pollutants. There were dramatic increases in research on heavy metals in the late 1970s, 1980s, and 1990s. This research allowed USEPA to promulgate risk-based regulations to protect public health and the environment.

The production of biosolids through various stabilization processes allows wastewater residuals to be beneficially used. The majority of the biosolids produced in the United States is land applied either directly to agriculture or further processed through composting or heat drying for use in agriculture or horticulture.

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